AD NUMBER

AD063453

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational use; April 1954. Other requests shall be referred to Wright Air Development Center, Wright-Patterson AFB OH 45433.

AUTHORITY

AFWAL ltr, 17 Apr 1980

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

AD 63453

Armed Services Technical Information Agency

Reproduced by
DOCUMENT SERVICE CENTER
KNOTT BUILDING, DAYTON, 2, OHIO

Because of our limited supply, you are requested to
RETURN THIS COPY WHEN IT HAS SERVED YOUR PURPOSE
so that it may be made available to other requesters.
Your cooperation will be appreciated.

UNCLASSIFIED

63453

FC

WADC TECHNICAL REPORT 54-524
PART 1

REDUCTION OF DRAG DUE TO LIFT AT SUPERSONIC SPEEDS

E. W. GRAHAM
P. A. LAGERSTROM
B. J. BEANE
R. M. LICHER
A. M. RODRIGUEZ

DOUGLAS AIRCRAFT COMPANY

APRIL 1954

WRIGHT AIR DEVELOPMENT CENTER

AF-WP-(B)-O-13 MAY 55 50

WADC TECHNICAL REPORT 54-524
PART 1

REDUCTION OF DRAG DUE TO LIFT AT SUPERSONIC SPEEDS

E. W. Graham
P. A. Lagerstrom
B. J. Beane
R. M. Licber
A. M. Rodriguez

Douglas Aircraft Company

April 1954

Aeronautical Research Laboratory
Contract No. AF 33(616)-2170
Project No. 1366
Task No. 70166

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Santa Monica Division of the Douglas Aircraft Company, Inc., under Contract No. AF 33(616)-2170 for the Wright Air Development Center. The authors of this report are Messrs. E. W. Graham, P. A. Lagerstrom, B. J. Beane, R. M. Licher, and A. M. Rodriguez. The work was accomplished under Project No. 1366, External and Internal Aerodynamics, Task No. 70166, Supersonic Wing Drag Reduction. Captain D. T. Barish and Mr. Fred L. Daum, both of the WADC Aeronautical Research Laboratory, served as Task Scientists.

This is a final report of a theoretical investigation of the reduction of the drag of wings at supersonic speeds through the proper distribution of camber and through the application of the "supersonic-biplane" concept.

ABSTRACT

Several topics relating to the reduction of drag due to lift at supersonic speeds are discussed. The distribution of camber for optimal loading of diamond planform wings and some low drag geometries for rectangular wings are determined. It appears that substantial drag reduction, through the use of spanwise distribution of camber, may be achieved only for low reduced aspect ratios, $\sqrt{M^2-1}$ AR. The distribution of lift throughout volumes of prescribed shape is considered and some optimum distributions found for certain cases. It is shown that optimum spatial distribututions of lift are generally not unique. The possibility of using biplanes is explored and it is concluded that for non-interfering biplanes (wings acting as isolated monoplanes) there is an inherent structural advantage which is the result of a scale effect for geometrically similar structures. The present status of means for drag reduction is surveyed and the direction for further study indicated.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Leslie B. Williams

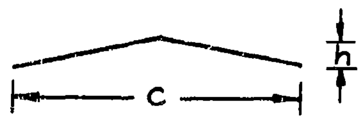
LESLIE B. WILLIAMS
Colonel, USAF
Chief, Aeronautical Research Laboratory
Directorate of Research

This report contains a summary of Douglas Report SM-18319 entitled, "Reduction of Drag Due to Lift at Supersonic Speeds". This summary was written for those who wish to get a brief survey of the results of the work described in SM-18319.

The results having engineering application are as follows: It was shown that generally twist and camber can be used in monoplane wings at supersonic speeds to reduce drag due to lift. For the special cases of wings with symmetry about a spanwise axis, however, like those with rectangular or diamond planform, only camber can lower the drag due to lift. The reduction in drag due to lift resulting from twist and camber varies with the planform shape, the aspect ratio, and the Mach number. This reduction is shown in Figure 1 for the cases calculated to date. It is seen that the percentage drag reduction associated with twist and camber is: largest for lower supersonic speeds and small for high supersonic speeds; largest for low aspect ratio wings and small for high aspect ratio wings; larger for diamond and delta than for rectangular planforms of equal aspect ratios.

The magnitude of distortion from the flat plate that is necessary to lower the drag is reasonably small, and increases with an increase in the operating lift coefficient at which the drag is to be lowered. As an example illustrative of the largest improvement calculated, take a rectangular zero camber wing of aspect ratio equal to one-half, at a Mach number of 1.41. A 36% reduction in drag due to lift is obtained by using the simple type of camber shown in the sketch below. At a design lift coefficient of 0.2, the necessary camber, (h/c), is 4%:

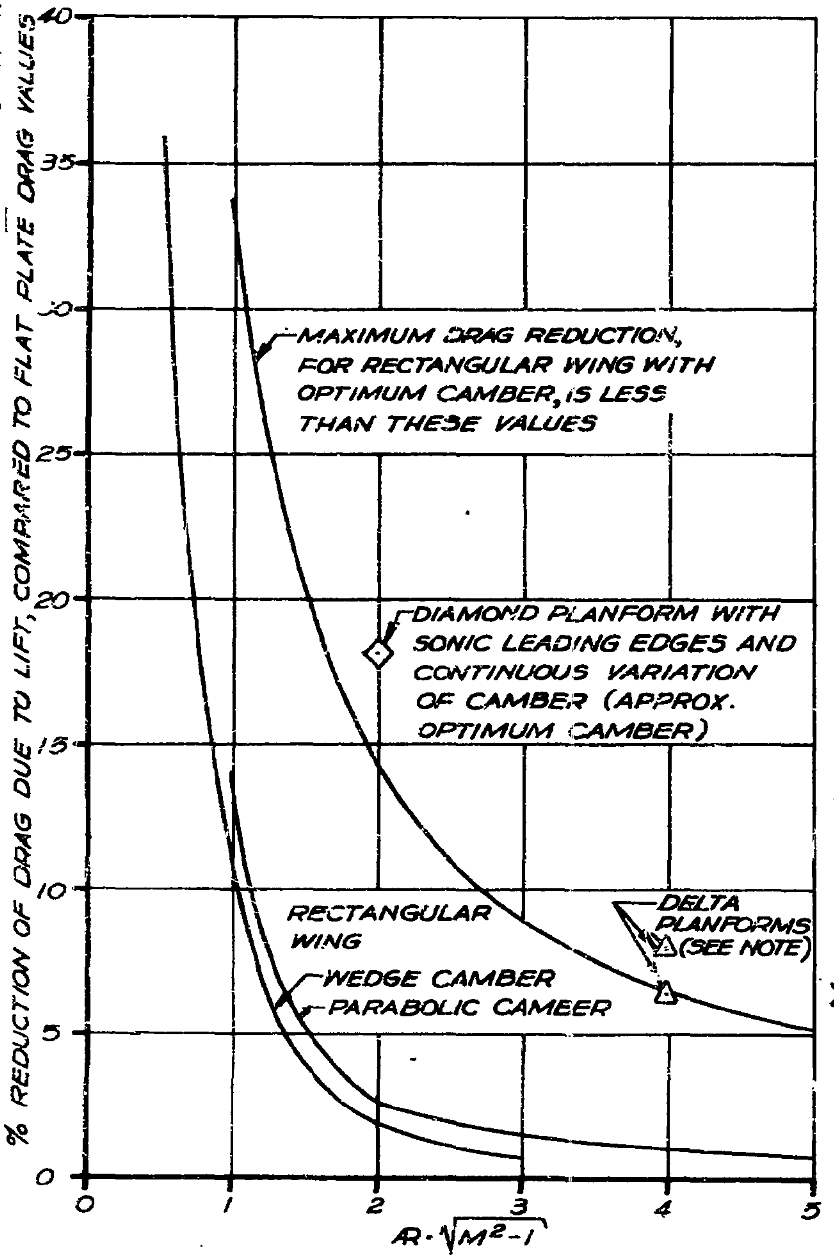
camber line, flat plate



camber line, lower drag wing

FIGURE 1

SUMMARY OF PRESENT INFORMATION ON REDUCTION OF DRAG DUE TO LIFT BY USE OF TWIST OR CAMBER



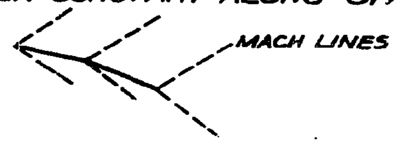
NOTES:

$A\!R$ = ASPECT RATIO = $(SPAN)^2/AREA$
M = FREE STREAM MACH NUMBER

SOLID CURVES PERTAIN TO RECTANGULAR WINGS, SYMBOLS TO ISOLATED CALCULATIONS FOR DIAMOND AND DELTA PLANFORMS

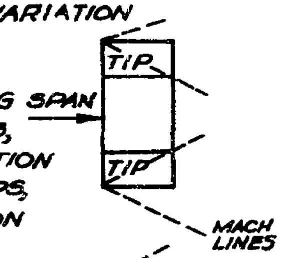
RECTANGULAR WINGS

WEDGE CAMBER CONSTANT ALONG SPAN



PARABOLIC CAMBER-SPANWISE VARIATION DEPENDS ON ASPECT RATIO

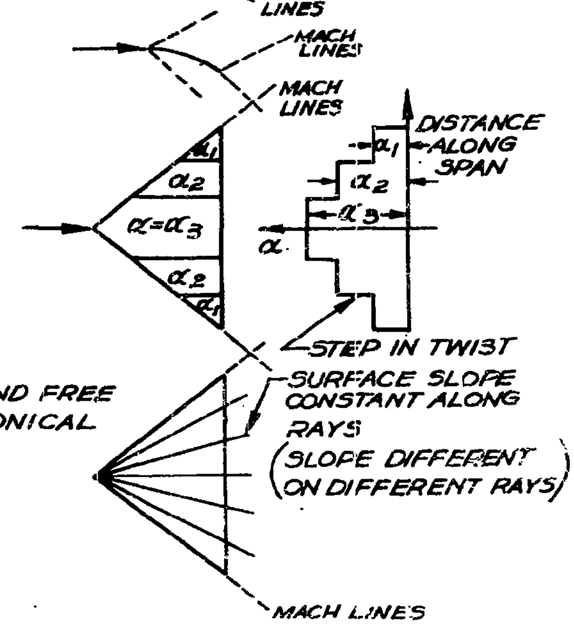
$1 \leq A\!R \leq 2$ CAMBER CONSTANT ALONG SPAN
$2 \leq A\!R \leq 3$ CAMBER POSITIVE AT TIPS, NEGATIVE AT CENTER SECTION
$3 \leq A\!R$ CAMBER POSITIVE AT TIPS, ZERO AT CENTER SECTION



DELTA WING

△ SONIC LEADING EDGES
NO CAMBER
STEPPED TWIST

△ SONIC LEADING EDGES
ANGLE BETWEEN SURFACE AND FREE STREAM CONSTANT ALONG CONICAL RAYS FROM VERTEX
(CALC. OF REF. 4)



For wings of any planform, delta, rectangular, or otherwise, the camber and twist for lowest drag due to lift can, in principle, be calculated from an integral equation (Eq. 3-18, page 17) which is derived in the report. For the general wing, the solution to this equation is not known and was not found during this study, but to a good approximation it was solved for the case of the diamond planform whose leading edge lies on a Mach cone. Previous work at the Douglas Aircraft Company, at the California Institute of Technology, and at Cornell University had given results on rectangular and delta wings (see references).

Consideration was also given to methods of reducing supersonic drag by use of wings other than monoplanes. It was shown in principle that reduction in drag due to lift can be obtained with multiplanes, although due to time limitations no specific cases were investigated. It was also shown that biplanes whose wings were not in each other's Mach cones exhibited the possibility of structural weight advantage.

In addition to results of engineering importance, certain results having theoretical importance were obtained. These are discussed in the subsequent paragraphs.

For the underlying mechanism of drag production on planar wings the "close" view, i.e., the local pressures and slopes, was taken. The mathematical relation for the conditions under which the drag is a minimum was found. For planar wings a general result was obtained. It was shown that the distribution of local surface slope (the camber and twist) for minimum drag due to lift is given by an integral equation. Certain influence functions, that relate the lift at a variable point to a unit slope at an arbitrary point, enter the equation. These are calculable by known methods.

Solution of the equation for the function which prescribes the optimum slope distribution, however, requires methods for the solution of integral equations. Such general methods are not known.

There are, however, other methods for calculating the twist and camber to any degree of approximation. Two such are the method of orthogonal loadings and the method of independent loadings. Both depend upon a result previously derived, and extended in SM-18319, relating the interference drag between certain kinds of slope distributions and the lifts produced by these distributions. As an application of these techniques, the approximate optimum camber of the diamond planform wing with sonic edges was calculated. These techniques have also been applied elsewhere to the calculation of the optimum slope distribution for a delta planform wing and a rectangular wing.

For rectangular planform wings it appeared that spanwise variation in camber could be used to reduce the drag. For this purpose the properties of certain spanwise lifting elements were investigated and then used to calculate the improvement in C_L^2/C_D. In addition, an estimate of the upper limit for improvements of this kind was made. As in the case of the diamond planform the difficulties presented by the integral equation were evaded by developing an appropriate special method suitable for approximation.

Large reductions in drag due to lift appear to be confined to small values of the reduced aspect ratio, $\sqrt{M^2-1} \cdot A\!\!R$. Under these conditions the wing-fuselage interference effects are large and the further development of methods concerned with wing alone will not be particularly useful. The study that is now necessary is the development of design methods that will include wing-fuselage interference effects.

Additional studies somewhat more removed from immediate application were also undertaken. These were concerned with the possibility of reducing the drag due to lift by using multiplane arrangements. Ordinarily the lift is distributed mainly over a single surface - the wing. One may imagine a more general situation in which the lift is distributed throughout a volume. Under certain circumstances an airfoil cascade may be the physical realization of such a distribution. For these studies it was convenient to adopt the "distant" viewpoint for the calculation of lift and drag. That is, the forces were computed from the momentum flux passing through a control surface at a great distance from the distribution of lifting elements. It was found that in some cases these distributions can have less drag due to lift than the best monoplanes contained within the volume and supporting the same lift; and that there are many distributions within a given volume that will have the same minimum drag (however, the different physical systems corresponding to the different distributions were not studied).

This phase of the study led to an examination of the behavior of lifting elements. It was found that a supersonic source could be replaced by a distribution of lifting elements plus a sink; that a source would have zero drag interference with the optimum distribution of lifting elements within certain volumes; and for other volumes the drag due to lift could be reduced by the inclusion of a thickness distribution.

REFERENCES

1. Graham, E. W., "A Drag Reduction Method for Wings of Fixed Plan-form," Journal of the Aeronautical Sciences, Vol. 19, No. 12, p. 823, December 1952. Originally Douglas Aircraft Company Report No. SM-14441, July 15, 1952.

2. Walker, K., "Examples of Drag Reduction for Rectangular Wings," Douglas Aircraft Company Report No. SM-14446, January 15, 1953.

3. Beane, Beverly J., "Examples of Drag Reduction for Delta Wings," Douglas Aircraft Company Report No. SM-14447, January 12, 1953.

4. Tsien, S. H., "The Supersonic Conical Wing of Minimum Drag," Thesis, Cornell University, Graduate School of Aeronautics, June 1953.

5. Rott, N., "Minimum Drag Cambered Rectangular Wing for Supersonic Speeds," Journal of the Aeronautical Sciences, Readers' Forum, Vol. 20, No. 9, p. 642, September 1953.

6. Strand, Thorstein, "Reduction of Drag Due to Lift for a Delta Wing with Sonic Leading Edges," Ae.E. Thesis, California Institute of Technology, p. 57, June, 1954.